TeMoG – An Accessible Tool for Creating Custom Soft Robotics Parts

Jonas Jørgensen(✉)

SDU Biorobotics, University of Southern Denmark, Campusvej 55, 5230 Odense, Denmark
jonj@sdu.dk

Abstract. Soft robotics research aims to create robots made of elastic and pliable materials such as silicone rubber. Soft robotics components are endowed with a singular biomorphic aesthetic and have recently made their way into art, design, and architecture projects. However, the design and fabrication of soft robotic parts presents a substantial challenge to most beginners. A number of resources containing instructions for how to fabricate soft robotic parts currently exists, yet they focus on reproducing existing soft robotic designs. This sets a limitation on the number of soft robotics components that a creative practitioner, who is not an experienced user of the technology, might utilize in their work. To address this lack, we developed a tool that allows the user to easily fabricate custom soft robotic parts. This tool, called the Tentacle Mold Generator (TeMoG), can be used by someone with no prior experience in soft robotics. It generates STL files for 3D printing a mold to cast a custom soft robotic tentacle in silicone. In this paper, we describe the TeMoG tool and how to use it. We demonstrate the tool's versatility and usefulness by presenting examples of its previous use in creative projects. TeMoG is distributed under a Creative Commons license and a link to download the tool with a detailed instructions manual is provided.

Keywords: Soft robotics · Fabrication · Design · Interactive art · Interaction design

1 Introduction

Soft robotics has within the past decade become a fast growing research field [1]. Soft robots can be defined as systems capable of autonomous behavior that are composed of materials with an elastic modulus in the range of that of soft biological materials [2]. Albeit still only commercially available as soft grippers for industrial automation [3–5], soft robotics technology has been proposed for several applications, including assistive technology, wearable technology, emergency relief, and collaborative robots (cobots). Soft robotics technology has a radically different appearance and behavior than conventional mechatronics and is endowed with a singular biomorphic aesthetic. Hence, soft robotics technology has also recently been appropriated in a number of art, design, and architecture projects [6].

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The design and fabrication of soft robotic parts, however, still presents a substantial challenge to most beginners that want to explore and utilize the technology. A number of accessible resources containing instructions for fabricating soft robotic parts currently exists, notably the *Soft Robotics Toolkit* (https://softroboticstoolkit.com/), instruction sets found on DIY websites including *Instructables*, *MAKE*, and *Adafruit*, and a recently published introductory DIY book [7]. These entry-level introductions to the area, however, only provide access to a limited number of existing soft robotic designs that can be replicated (excepting [8]). This sets an unfortunate limitation on the types of soft robotic components that an artist, designer, or architect who is not experienced in working with the technology might incorporate into their work.

To address this lack, we developed a tool that makes it easy to fabricate custom soft robotic parts. The tool can be used by someone with no prior experience in soft robotics. It generates files for 3D printing a mold to cast custom soft robotic parts, more specifically variations of a soft tentacle morphology. In this paper, we describe this tool, dubbed *Tentacle Mold Generator* (*TeMoG*), and how to use it. We also provide suggestions for how to power, alter, and augment soft robotic tentacles created with it. Lastly, we demonstrate the tool's versatility and usefulness for creative practice projects by describing select examples of its previous usage. TeMoG is distributed under a Creative Commons license and a link is included to download the tool and a detailed instructions manual. By sharing TeMoG with practitioners outside the soft robotics community and showcasing examples of its use in creative projects, we aim to make soft robotics more accessible to creative practitioners and to encourage novel usages of the technology within interactive art, interaction design, and related fields.

2 Soft Robotic Tentacles

Tentacle-inspired soft actuators are a basic and versatile component class used for many types of soft robotic systems and tasks including manipulation, locomotion, and positioning [9]. The first soft tentacles were developed in the early 1990s, by the Suzumori lab at Okoyama University, where researchers constructed small tri-cellular elastomer units, and demonstrated that different designs for manipulators and walkers could be assembled from them [10, 11]. Since then, pneumatically actuated tentacle structures have frequently served as both dexterous legs and cylindrical manipulator modules in soft robot designs [12, 13]. A soft robotic tentacle works similarly to a biological muscular hydrostat, as it realizes movement by expanding different sides of the overall structure, to create bending in the opposite direction. This expansion is realized by inflating internal chambers with pressurized air coming from electrical pumps or a compressor. A tentacle with just three internal chambers can thus realize a three-dimensional movement range.

Existing projects within art, design, and architecture that incorporate soft robotics technology have mainly used bending actuators with *pneumatic networks* (*pneunets*) or simple inflatable pouches [6]. However, a tentacle design has been used in media artist Paul Carlo Esposito's piece *Symbiont* (2018), a performance installation that sees the artist enveloped by a suspended tubular structure featuring protruding tentacles (Fig. 1).

Fig. 1. Paul Carlo Esposito, *Symbiont* (2018). Images courtesy of the artist.

3 Tentacle Mold Generator (TeMoG) – Tool Overview

TeMoG enables a user to easily generate 3D printable molds to cast custom soft robotic tentacles. The tool consists of parametric files that are executed in OpenSCAD, an open-source geometric CAD software program that can be downloaded for free (https://www.openscad.org/). With the OpenSCAD files, the user can generate STL files of the mold parts needed to fabricate a tentacle and subsequently 3D print them (Fig. 2).

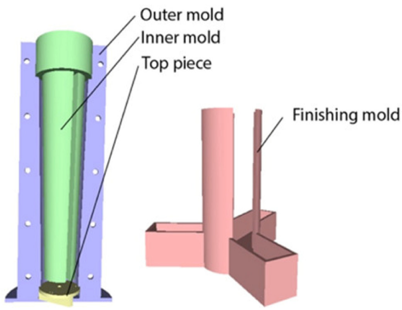


Fig. 2. Mold parts (only one out of two identical outer mold parts is shown).

The CAD modeling of the parts is done by parametric programming, hence all dimensions of the tentacle (e.g. maximum- and minimum diameter, length etc.) can easily be altered by simply changing variable values listed at the top of the script (see Fig. 3 and examples in Table 1).

4 Fabrication Procedure

Below we describe the steps involved in fabricating a soft robotic tentacle with TeMoG. A detailed description of each step can be found in the instruction manual included as a PDF file with the tool.

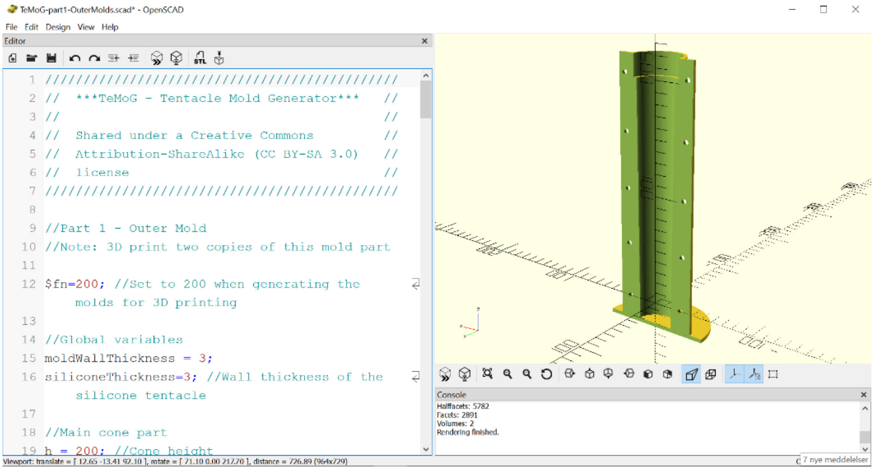


Fig. 3. Screenshot from OpenSCAD showing the variable list in the script (left) and the CAD rendering of one side of the outer mold (right).

4.1 Designing the Mold

- The "ResultingCast" file is loaded in OpenSCAD. This file is not a mold file, but instead gives a rendering of the complete tentacle.
- Variables are adjusted to achieve the desired tentacle morphology (see Table 1 for an overview of the main variables).
- The variable list is marked and copied.
- The first mold file is opened and the variable list inserted. The mold part is rendered and exported as an STL file.
- Similarly, the variable list is copied to the other parametric files and the remaining mold parts generated.

4.2 3D Printing Mold Parts

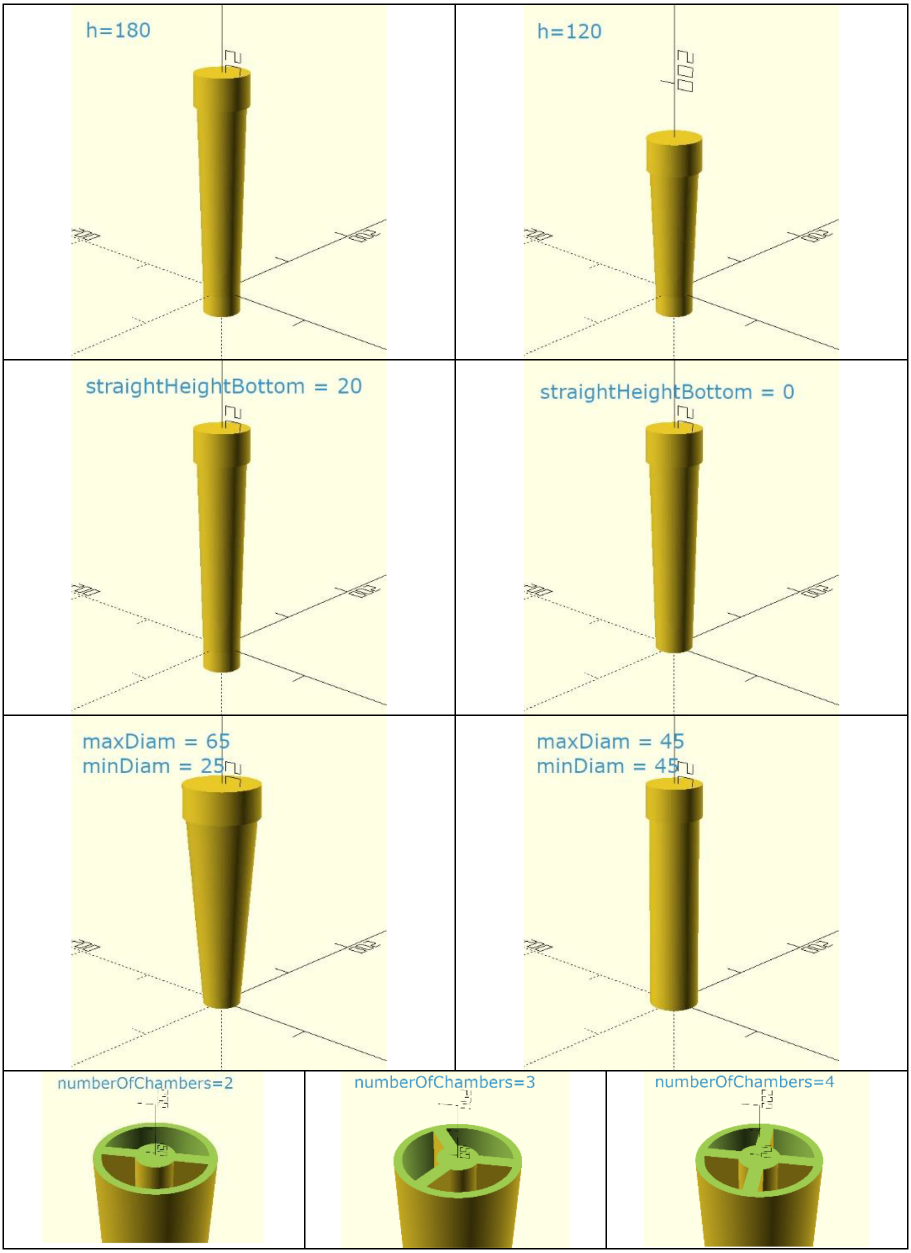
The mold parts can be printed on a consumer grade 3D printer in PLA or another rigid material.

- The STL file for the mold part is imported in the slicing software (e.g. Cura or Simplify3D) and oriented correctly for printing.
- Appropriate print settings are chosen, we recommend printing in solid to increase strength and durability. Adding a brim to prevent curling and improve adhesion during printing helps to obtain a successful print.

4.3 Fabricating the Tentacle

We have used Ecoflex 00-30 and 00-50 silicones to cast tentacles, but other high stretch rubbers can also be used. Only requirement for the fabrication technique described here

Table 1. CAD renderings of a tentacle with different values chosen for the main variables of the tool.



to work is that the mixed liquid rubber should be able to act as a glue between the cured rubber pieces, like Ecoflex silicones will.

Casting Process

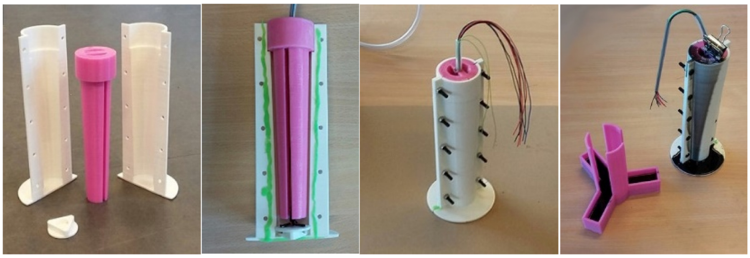


Fig. 4. The casting process.

- The interior of the two outer molds and the inner mold is coated with a mold release agent
- Play-Doh is applied to the edges of one of the outer molds to act as a seal
- The mold is closed with bolts and nuts
- Ecoflex silicone mixed with silicone pigments (shown here in black) is poured through the hole at the top of the inner mold and into the bottom of the finishing mold (right image Fig. 4)
- After 24 h of curing at room temperature the demolding can be done

Demolding, Bonding, and Attaching Tubing

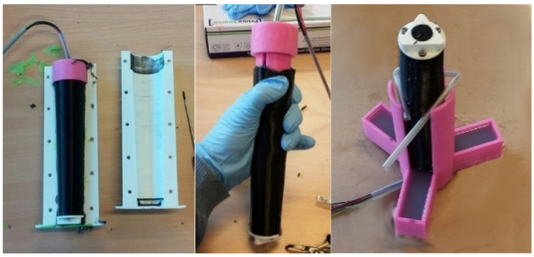


Fig. 5. Demolding and bonding of the two tentacle parts

- The mold is opened (Fig. 5)
- The inner mold is pulled out of the tentacle

- Liquid Ecoflex is brushed on the contact surfaces between the tentacle and the bottom part of the tentacle that has been cast in the finishing mold
- Ecoflex is poured into the finishing mold and the tentacle is placed standing upright in the finishing mold (right image)
- After 24 h, the tentacle is removed from the finishing mold
- The air chambers are perforated individually from below and tubing for inflation inserted and glued in place

5 Additions

Once finished, the tentacle can be actuated by hand with a syringe or with an electro-pneumatic control setup consisting of a microcontroller with a motor shield, an electrical pump, and solenoid valves. Detailed instructions for assembling a low-cost setup are available online [14]. Pneumatically actuated soft robots have also previously been powered by more exotic means such as controlled explosions [15–18] and chemical reactions [19].

For uses in aesthetic practice projects, a limitation of TeMoG would appear to be, that tentacles made with the tool are limited to being either conical or tubular and having a flat surface. However, this apparent limitation is easily circumvented, as tentacles made with the tool can be modified to obtain other design aesthetics. They can also be augmented with sensors to gain interactive capabilities. Here we describe three easy ways for getting started with this.

5.1 Fiber Reinforcements

Fiber reinforcements can be added to the tentacle to prevent radial expansion. This will create a more focused movement, as the tentacle will not expand, but only extend when inflated (see Fig. 6).

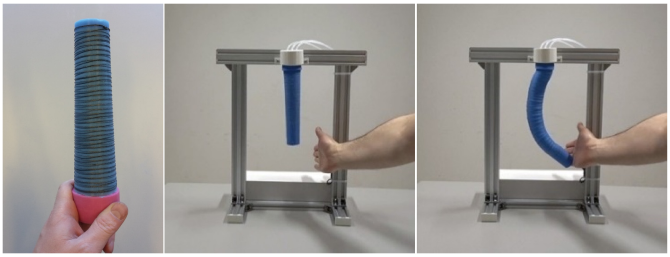


Fig. 6. Fiber reinforcements are added to the cast tentacle before a second layer of silicone is added (left). The finished tentacle in uninflated (middle) and inflated (right) state.

When the tentacle has been removed from the outer mold, braided fishing line is wrapped around the tentacle from the bottom to the top and back again in the opposite direction (Fig. 6, left image). A second layer of silicone is cast on top of it to conceal the windings (detailed instructions for doing this are included in the instruction manual).

5.2 Surface Texture

Surface texture can be added to the tentacle by casting another layer of soft silicone on top of the finished tentacle. However, it is important that the tentacle is completely clean to obtain good adhesion when casting a second layer, and mold release agent should not be used on the outer mold, when casting the tentacle. A mold for casting surface texture can be created in clay or alginate by depressing objects into these substrates before allowing them to harden. Texture molds can be made after human skin, for instance, to give the tentacle an uncanny look (Fig. 7, left). Or with deep thin channels to create small polyps or tentacles on the surface like e.g. sea anemones have (Fig. 7, right).

Fig. 7. Skin texture cast in silicone using a mold made from alginate by depressing an elbow into it (left). Small tentacles cast in silicone onto a soft robotic actuator using a mold made from clay (right). Right image courtesy of Studio ThinkingHand, detail from their work *INTERTIDAL SYNTHESIS* (2020), 3 channel video and sculpture installation.

5.3 Sensing

To make the tentacle interactive, sensors can be added to it. With sensing implemented, a tentacle could, for instance, be used for an interactive game, as an experimental interface, or become autonomous and have feedback-controlled movements. Soft silicone robots can be sensorized via the addition of channels of liquid metal (e.g. eutectic gallium-indium) to detect touch and deformation [20]. Two more accessible options for a tentacle, are to either cast a resistive flex sensor inside in the middle (if it is two-chambered) or to use one or more pressure sensors connected to the tentacle's pneumatic supply tubing. To test the latter idea, we attached a cheap barometric pressure sensor (GY68 BMP180) to an Arduino microcontroller. We connected it to one of the supply tubes of a tentacle fabricated in Ecoflex 00-30 using the standard preset variable values in TeMoG. When the tentacle was inflated, we noted an increase in pressure detected by the sensor upon compressing the tentacle chamber by hand.

6 Example Projects

Soft robotic parts made with the tool have already been used for several projects, both within creative practice and in a research context. These include robotic art installations, a plant-inspired light-seeking robot prototype [21], a platform to conduct human-robot interaction experiments [22–24], and an embodied neuromorphic computing experiment [25]. Two additional examples are described below to showcase the designs that the tool can produce and different ways they might be used within creative projects.

6.1 LARPing AI

Larping AI is a series of live action role-plays (LARPs) and workshops by artist Susan Ploetz that interrogate emergent relations surrounding AI algorithms and robotics through somatic practices and embodied simulation. When *Larping AI* was exhibited in Tokyo in late-2019, a soft robotic three-chambered tentacle fabricated with TeMoG was integrated into the live action role-plays (Figs. 8, 9). The semitranslucent uncolored tentacle was equipped with a temperature sensor and the tentacle would respond with movement when held in the hands and exposed to body heat [26].

Fig. 8. Photos taken during one of the runs of the live action role-play showing the soft tentacle and participants. Images courtesy of the artist. Photo: Yuki Maniwa.

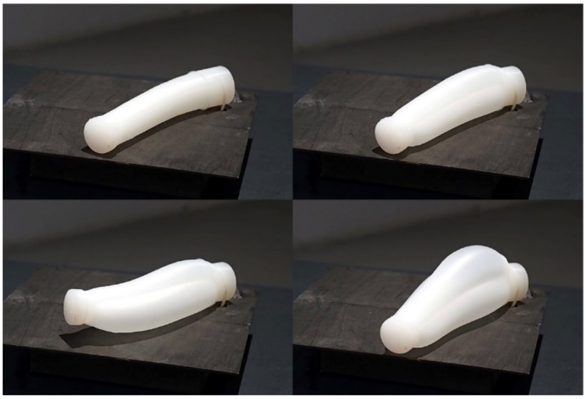


Fig. 9. Example of the soft tentacle's movements. Video available at: https://youtu.be/Rq_-geG6N-s

6.2 Tales of C

Tales of C (2017–2018) (Fig. 10) is a soft robotic artwork by the author featuring a cephalopod-inspired soft robot, whose upper body was created with TeMoG [27]. The artificial creature moves in a tank by inflating and deflating its body and swaying its arms. It emits light and a speak performed by a synthetic voice narrates the installation. *Tales of C* explores the cultural imaginary of cephalopods (the molluscan class that counts the squid, cuttlefish, octopus, and nautilus). It weaves an unstable narrative that occasionally unmasks uncanny overlaps between cultural perceptions of cephalopods and fears voiced about computational media technologies.

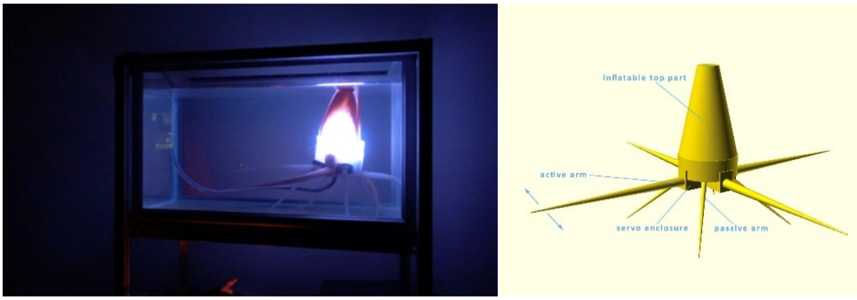


Fig. 10. Installation view of *Tales of C* (left). CAD rendering of the cephalopod robot (right). A video showing the installation is available at: https://youtu.be/B4S0E5D4zck

7 Conclusion and Further Work

In this paper, we presented the TeMoG tool. By doing so, we sought to contribute to democratizing soft robotics technology by enabling creative practitioners to easily fabricate custom soft robotic parts. Our paper described how to use the tool and we shared an instruction manual detailing this use written for people with no experience in soft robotics. Lastly, we presented ways to power, augment, and sensorize tentacles made with the tool and described two arts-led projects that have used them. The TeMoG tool can be used as it is but given that the code is distributed under a Creative Commons Attribution-ShareAlike (CC BY-SA 3.0) license, it easily lends itself to further modifications. Any user can in principle fork the repository and start adding additional features and more detailed functionalities to the tool, in order for it to support the fabrication of even more types of morphologies. The option to make tentacles with a single inner pneumatic chamber placed asymmetrically (as in [28]), for instance, could be implemented as well as the choice to have a round instead of a flat tip on the tentacle. We encourage such modifications and hope to see the community of creative practitioners use the tool for novel exciting projects. With any luck, this will accelerate the recently initiated aesthetic explorations of soft robotics in arts-based experiments that, as we have argued extensively in prior work [6], can contribute to developing a transdisciplinary perspective on soft robotics, that is more adequate to their full range of relational capacities.

Download

TeMoG and the instruction manual can be downloaded from:
https://github.com/RobotisMollis/TeMoG

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